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Research Paper

EXPERIMENTAL ANALYSIS OF EVAPORATIVE CONDENSER BASED VAPOUR COMPRESSION REFRIGERATION SYSTEM

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ABSTRACT

Refrigerators work on vapour compression refrigeration cycle. In the refrigerator, evaporator, condenser, compressor and capillary tube are important parts. The performance of refrigerator depends on the performance of these four main parts. The evaporator and condenser work as a heat exchanger. Generally, air is used to cool the refrigerant vapour in condenser. But due to low heat carrying capacity of air, mass of air is high and large condenser is required. The size of condenser and performance of refrigerator is improved by using water as a cooling medium. The objective of this study is to investigate the performance of refrigerator by using Evaporative condenser in which water is used as cooling fluid. A refrigerator of 220 liter capacity was used to develop the experimental setup. The experiment was carried out on developed setup with air cooled condenser and evaporative condenser. Then results of both experiments were compared. The result shows that the coefficient of performance (COP) of refrigerator is improved by 4.1% using evaporative condenser.

Key words: Vapour compression refrigeration system, Air cooled condenser, Evaporative condenser, Coefficient of performance, Refrigerator.

Abbreviations

COP	Coefficient of Performance
TR	Ton of Refrigeration
VCR	Vapour Compression Refrigeration

Nomenclatures

Qc	Condenser heat rejection	kcal/hr or kW
Qe	Evaporator heat absorbed	kcal/hr or kW
T, t	Temperature	^{0}C
Tc	Condenser Temperature	^{0}C
Te	Evaporator Temperature	^{0}C
Pe	Evaporator pressure	bar
Pc	Condenser pressure	bar
h	Enthalpy	kJ/kg
Cp	Specific heat	kJ/kg^{0}K
m_r	Refrigerant Mass flow rate	kg/min

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INTRODUCTION

The standard household refrigerator operates primarily on a vapor compression refrigeration cycle (VCR), a mechanical process designed to maintain a low-temperature environment within an insulated cabinet. This system

continuously circulates a specialized refrigerant typically R-134a in modern units through a closed-loop system consisting of four fundamental stages: compression, condensation, expansion, and evaporation. [8]

The efficiency of this cycle is heavily influenced by the heat rejection capabilities of the system's components. The compressor, often referred to as the heart of the refrigerator, elevates the pressure and temperature of the refrigerant vapor. This high-pressure gas then enters the condenser, a heat exchanger responsible for releasing absorbed thermal energy into the surrounding environment. [9]

In domestic applications, condensers are typically air-cooled and fall into two main design categories:

- Static Wire-and-Tube Condensers: Found on the rear of many units, these rely on natural convection to dissipate heat.
- Hot-Wall (Skin) Condensers: Integrated into the side walls of the refrigerator, these utilize the appliance's outer sheet to diffuse heat, offering a more streamlined "flat back" aesthetic and protecting the coils from dust accumulation. [10]

While industrial refrigeration often employs water-cooled or evaporative condensers for their superior heat transfer rates, domestic units prioritize simplicity and low maintenance. However, as global energy regulations become increasingly stringent, research into enhancing the Coefficient of Performance (COP) of household units is vital. Innovations such as Phase Change Materials (PCM), optimized condenser geometries (e.g., helical coils), and advanced thermal coatings are currently being explored to reduce compressor workload and electrical consumption. [9]

This paper examines the thermal dynamics of these condensing units and investigates the potential for alternative cooling strategies to improve the energy efficiency of the modern household refrigerator.

LITERATURE SURVEY

Enhancing the efficiency of cooling systems is achievable through strategic updates to condenser geometry and thermal management.

Investigations by Sheety and Kamath [1] revealed that utilizing water rather than air as a coolant boosted the Coefficient of Performance from 6.28 to 9.5. This change yielded a productivity surge of 51.27%. In a separate study, Patel's team [2] explored how coil shapes impact domestic fridge output. By testing various configurations, they determined that helical water-cooled coils outperformed all others. This is largely due to water's thermal conductivity, which is approximately quadruple that of air, ultimately decreasing the workload required by the compressor.

Balancing cooling efficiency with ecological preservation requires careful refrigerant selection. Research by Cabello's team [3] found that R22 remains more power-efficient than R134a or R407c as compression levels climb. From a sustainability standpoint, Bolaji [4,5] suggested transitioning to R152a, noting that several methane and ethane-based compounds offer a safer profile with negligible global warming influence.

Meanwhile, Calm [6] highlighted that mechanical failures in chillers lead to fluid leaks that degrade performance; he recommended aggressive maintenance and vapor recovery to curb these losses. Complementing this, Benhadid-Dib and Benzaoui [7] champion the use of "natural" alternatives. By eliminating chlorine and fluorine, these substances mitigate greenhouse effects and provide a cleaner substitute for traditional, polluting cooling fluids.

Literature surveys show that so far, many researchers have worked with vapour compression refrigeration systems with air cooled condenser. Many investigators found that evaporative condensers produce more cooling than air-cooled condensers. The rate of heat transfer in evaporative condenser is more. Evaporative condenser is suitable for using long periods. Also, evaporative condensers are used for large capacity plants. Literature survey also shows that few works was done to study the

performance of refrigerator with evaporative condenser. Therefore, this work is carried out by use of evaporative condenser in refrigerator which is better alternative of air-cooled condenser to improve the performance.

EXPERIMENTAL ANALYSIS

The experiment analysis of refrigerator with air cooled condenser and evaporative condenser are carried out in this section. For experimental analysis, set up was fabricated using refrigerator and other measuring instruments.

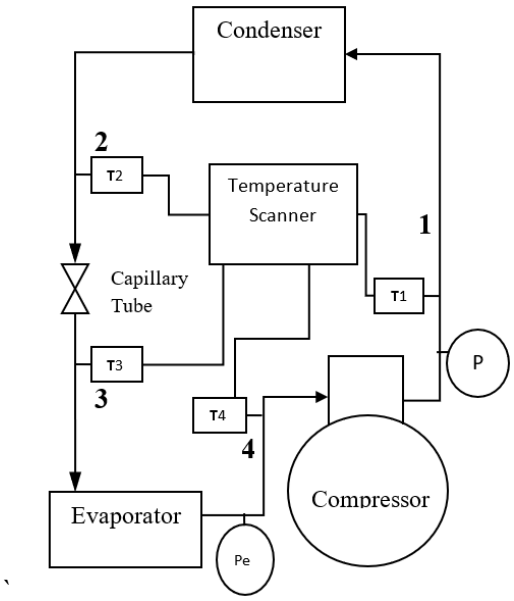


Figure 2: Schematic diagram of refrigerator test rig

Experimental set up development

The experimental test rig used in this study, as shown in figure 2, is developed at Heat engine laborotary, Polytechnic, The Maharaja Sayajirao University of Baroda, Vadodara, Gujarat, India. The test ring consists of a condenser, evaporator, compressor, capillary tube and water spray facility. All four parts are joined with ¼" (6 mm diameter) copper pipe. The insulation is used to connect pipes. Most of the equipment used in both cases is the same. In order to operate the system as a unit with an evaporative condenser, water is sprayed manually on the condenser tube.

The evaporative condenser also served as an air-cooled condenser by turning off the draining water from the system.

The test unit was filled with an 80-gram charge of R-134a. During the evaporative condenser's operation, a pump maintained a steady water flow strictly within the unit at the necessary velocity.

Electrical and mechanical data collection points are illustrated in Figure 2. Physical parameters - specifically temperature, pressure, and mass flow - were tracked using specialized equipment. Thermal data was captured by K-type thermocouples secured to the copper piping. For pressure monitoring, Bourdon gauges were positioned at the compressor's intake and discharge ports. Because the specialized design of the heat exchangers and the short pipe runs result in negligible flow resistance, the measured compressor pressures are considered representative of those in the evaporator and condenser. Additionally, a variable area flow meter for R-134a was integrated into the liquid line to log mass flow. Finally, to quantify compressor energy usage, an ammeter and voltmeter were used to record current and voltage levels.

Instrumentation

As depicted in Figure 2, the experimental setup featured several monitoring stations to track flow, pressure, and thermal data. To evaluate refrigeration efficiency, PT-100 sensors (rated for -100°C to 200°C) recorded temperatures at four distinct locations. These probes were integrated into two 10-channel digital scanners from Alfa Pvt. Ltd. (Ahmedabad). Pressure levels for the evaporator and condenser were monitored at the compressor's suction and discharge points using 0–400 psi gauges supplied by Air Master Pvt. Ltd. (Vadodara). Furthermore, R-134a mass flow was captured via Water Ashian Pvt. Ltd. (Mumbai) rotameters with a 0–100 cc/sec capacity. To ensure data integrity, Instrumenta Pvt. Ltd. performed the calibration for all diagnostic tools used in the study. In figure 2 the temperature measuring point numbers are indicated as follows:

1 Refrigerant vapour outlet from evaporator
2 Refrigerant vapour outlet from compressor.
3 Refrigerant liquid outlet Condenser
4 Refrigerant liquid outlet from capillary tube
5 Refrigerator cabinet Temperature

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6 Ambient Temperature.



Figure 3: Photograph of experimental set up

Experimental procedure

Air cooled condenser

To carry out experiment on test rig with air cooled condenser, refrigerator unit was connected with main supply. Then temperatures, pressures and flow rate were recorded after steady state achieved by unit. As presented in Table 1, the data represents mean figures derived from five separate observations captured at 15-minute increments.

Evaporative condenser

Testing on the evaporative condenser setup commenced after reconnecting the refrigeration system to the primary electrical source. Then water spray started on the condenser tube with manual sprayer. The readings of temperature, pressure and flow rate were recorded after steady state achieved by unit. Table 2 displays the arithmetic means calculated from five distinct measurements, each taken every quarter-hour throughout the testing period.

Table 1: Temperature, pressure and Flow rates at various locations in refrigerator with air cooled condenser

Parameters	Value
Condenser pressure, p_c (bar)	11.72
Evaporator pressure, p_e (bar)	1.11
Refrigerant flow rate, m_r (kg/min)	0.972
Temperature at compressor exit, t_1 (^{0}C)	63.2
Temperature at condenser exit, t_2 (^{0}C)	37.5
Temperature at capillary tube exit, t_3 (^{0}C)	-1.1
Temperature at evaporator exit, t_4 (^{0}C)	34
Temperature in cabinet, t_5 (^{0}C)	11
Ambient temperature, t_6 (^{0}C)	37

Table 2: Temperature, pressure and Flow rates at various locations in refrigerator with evaporative condenser

Parameters	Value
Condenser pressure, p_c (bar)	11.72
Evaporator pressure, p_e (bar)	1.11
Refrigerant flow rate, m_r (kg/min)	0.972
Temperature at compressor exit, t_1 (^{0}C)	63.3
Temperature at condenser exit, t_2 (^{0}C)	39.9
Temperature at capillary tube exit, t_3 (^{0}C)	0
Temperature at evaporator exit, t_4 (^{0}C)	34.2
Temperature in cabinet, t_5 (^{0}C)	11
Ambient temperature, t_6 (^{0}C)	39

RESULT AND DISCUSSION

This part of the study evaluates the cooling capacity, coefficient of performance, and compressor energy consumption. These metrics rely on critical pressure and thermal data collected at various coordinates, as mapped in Figure 2. By inputting these stabilized temperature and pressure readings into EES software, specific enthalpy values were determined for each state point.

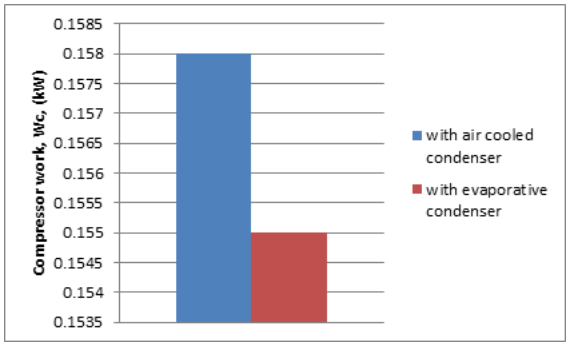


Figure 4 : Comparison of compressor work

A graphical contrast between the power requirements (compressor work) of air-cooled and evaporative condenser units is provided in Figure 4. The data indicates that the evaporative model demanded marginally less energy than the standard air-cooled version. This reduction is beneficial, as minimal compressor power consumption (work) translates directly to improved energy efficiency. Specifically, the

evaporative configuration achieved a 1.8% decrease in electrical workload.

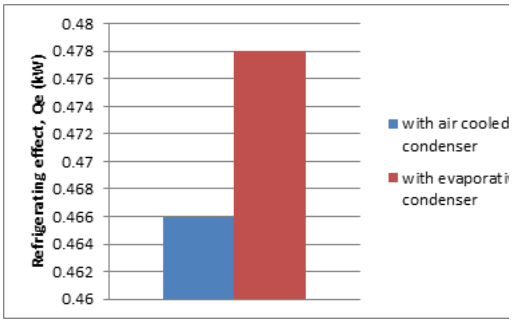


Figure 5: Comparison of refrigerating effect

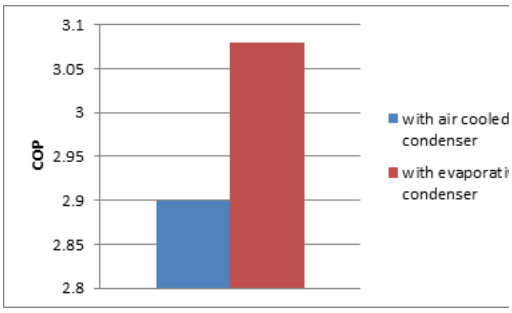


Figure 6: Comparison of COP

The comparison of refrigerating effect and COP for both cases are shown in figure 5 and figure 6 respectively. The result shows that the cooling capacity (*Qe*) of a refrigerator working with evaporative condenser is enhanced with air cooled condenser. Higher refrigerating effect gives better heat absorption in refrigerator cabinet by evaporator, consequently, the system reaches its desire temperature while operating for a significantly shorter duration. The refrigerating effect is improved 2.5% with evaporative condenser. Finally decrease in compressor work and increase in refrigerating effect leads to increase in COP of refrigerator units. The analysis results shows that the COP of refrigerator with evaporative cooling is enhanced by 4.1%.

CONCLUSION

The performance of a domestic refrigerator with evaporative condenser was investigated experimentally. The refrigerating effect of 0.478 kW and COP of 3.08 were obtained with evaporative condenser unit. The refrigerator with evaporative condenser unit gives 1.8% higher refrigerating effect and 4.1% higher COP than air cooled condenser unit.

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